

# Speed Control of Separately Excited dc Motor using Fuzzy Technique

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**Abstract-** This paper presents the speed control of a separately excited DC motor using Fuzzy Logic Control (FLC). The Fuzzy Logic Controller designed in this study applies the required control voltage based on motor speed error (e) and its change (ce). The performance of the driver system was evaluated through digital simulations using Simulink. The simulation results show that the control with FLC outperforms PI control in terms of overshoot, steady state error and rise time.

**Keywords:** DC motor, chopper, FLC.

## I. INTRODUCTION

DC motors are used in many applications like electric trains, vehicles, cranes and robotics manipulators. They require controlling of speed to perform their tasks. Initially speed control of DC motor has been done by voltage control [1]. Semiconductors too like MOSFET, IGBT and GTO have been used as switching devices to control speed[2].

Due to nonlinearity properties, control of system is difficult and mathematically tedious. To overcome this difficulty, FLC (Fuzzy Logic control) has been developed. FLC is applicable to time variant and nonlinear. Metro system in the sendia of japan is the best application [3].

In this study, the speed response of a separately excited DC motor exposed to fixed armature voltage is studied for both loaded and unloaded operating conditions. Performance of separately excited DC motor is compared for both methods FLC and PI controller for both loaded and unloaded conditions. In this study, chopper circuit has been used as a motor driver.

## II. MOTOR MODEL

The resistance of the field winding and its inductance are represented by  $R_f$  and  $L_f$  respectively. The armature, resistance and inductance are represented by  $R_a$  and  $L_a$  respectively. Armature reactions effects are ignored in the description of the separately excited DC motor. This negligence is justifiable to minimize the effects of armature reaction since the motor (SE) used has either interpoles or compensating winding. The fixed voltage  $V_f$  is applied to the field and the field current settles down to a constant value. A linear model of a simple separately excited DC motor consists of a mechanical equation and electrical equation as determined in the following equations:

$$J_m \frac{d\omega_m}{dt} = K_n \phi I_a - b\omega_m - M_{load} \quad (1)$$

$$L_a \frac{dI_a}{dt} = V_a - I_a R_a - K_b \phi \omega_m \quad (2)$$

The dynamic model of the system is formed using these differential equations and Matlab Simulink blocks as shown in Fig. I,

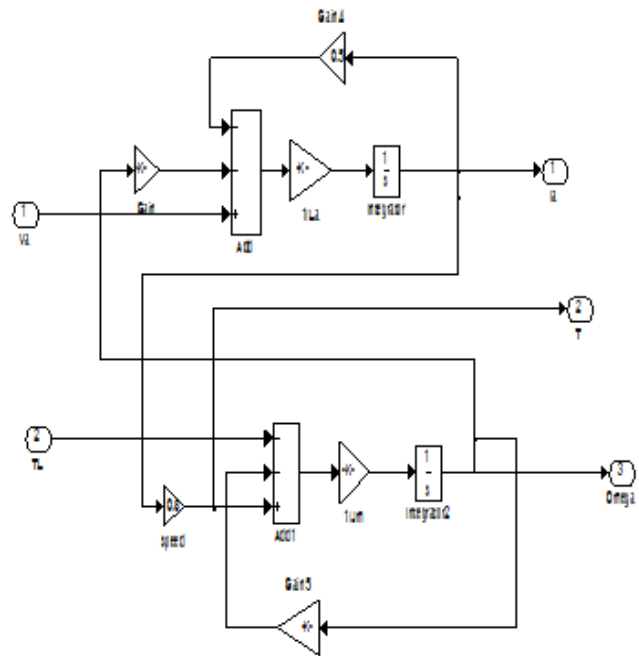


Fig 1: Simulink Motor model

TABLE I. MOTOR PARAMETERS

Parameter	Description	Value
$R_a$	Armature Resistance( $\Omega$ )	0.5
$L_a$	Armature Inductance(H)	0.003
$J_m$	Inertia of Motor( $\text{kg.m}^2/\text{s}^2$ )	0.0167
$K$	Motor constant(Nm/Amp)	0.8
$B$	Damping ratio of mechanical system(Nms)	0.0167

### III. FUZZY LOGIC CONTROLLER (FLC) DESCRIPTION AND DESIGN

Fuzzy logic control is based on logical relationships like “suitable, not very suitable, high, little high, much and far too much that are frequently used words in people’s life. Fuzzy Sets Theory has been introduced to express and process fuzzy knowledge [4], [5] which are used to show linguistic variables. The relation between fuzzy logic and fuzzy set theory that is similar that of relation between Boolean logic and set theory. Fig. 2 shows a basic FLC structure.

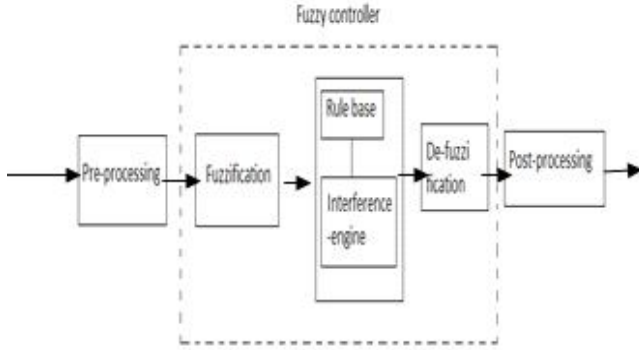


Fig. 2 Process Blocks for a Fuzzy Controller

FLC is processed for linguistic definitions, while other controllers work on the accuracy and parameters of system model. While designing FLC, there is no need of knowledge of system model, as a controller. However, less knowledge of control process may result unsatisfactory [6].

#### A. Defining inputs, outputs:

As the bigger speed error the bigger controller input is expected. So, FLC is designed to minimize speed error. Due to that FLC uses error ( $e$ ) and change of error ( $ce$ ) for linguistic variables which are generated from the control rules. Control variable ( $cu$ ) is applied to achieve angular value ( $\alpha$ ), which determines duty cycle.

$$\begin{aligned} e(k) &= [\omega_r(k) - \omega_a(k)] * K_{IE} \\ ce(k) &= [e(k) - e(k-1)] * K_{2CE} \\ ca(k) &= [\alpha(k) - \alpha(k-1)] * K_{3ca} \end{aligned} \quad (3)$$

Here  $K_{IE}$ ,  $K_{2CE}$  and  $K_{3ca}$  are each gain coefficients and  $K$  is a time index.

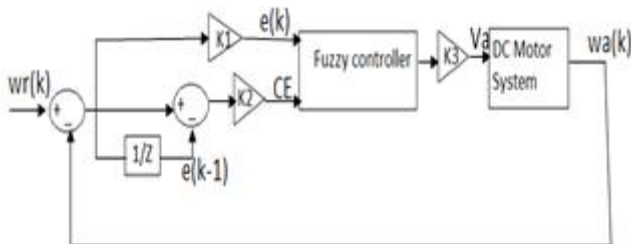


Fig. 3. Block diagram of the DC motor control

At nominal value of motor speed the error ( $e$ ) gives its smallest value, and at maximum value of motor speed the error gives its larger value, with range  $-200$  and  $200$ .

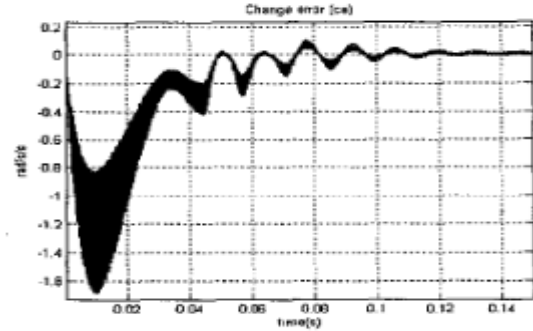


Fig. 4. Change of Error

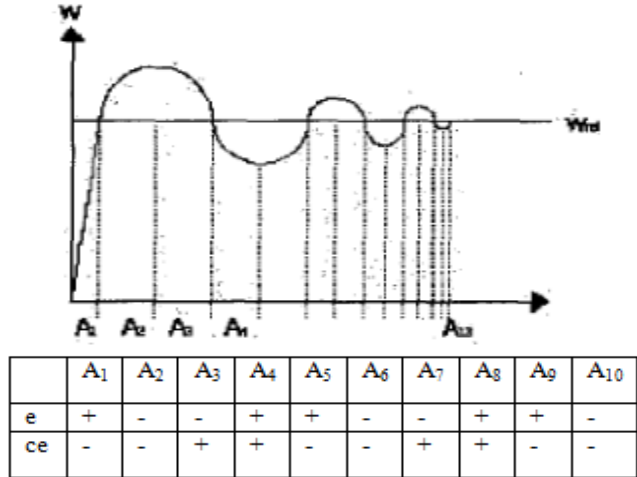


Fig. 5. Dynamic Signal Analysis

#### B. Defining membership functions and rules:

System speed comes to reference value by means of the defined rules. For example, first rule on Table determines, ‘if ( $e$ ) is PL and ( $ce$ ) is PL then ( $c$ ) is NL’ According to this rule, if error value is positive large and change of error value is positive large then output, change of alpha will be negative large. In this condition, corresponding A4 interval in Fig 5, motor speed is smaller than reference speed and still wants to decrease strongly. This is one of the worst conditions in control process. Because of the fact that alpha is smaller than the required value, its value can be increased by giving output PL value. This state corresponds to motor voltage decreasing. All conditions in control process are shown in Fig.5. Membership functions have been used to convert inputs and outputs from crisp value to linguistic term. Linguistic terms are represented here by seven membership functions shown in table.

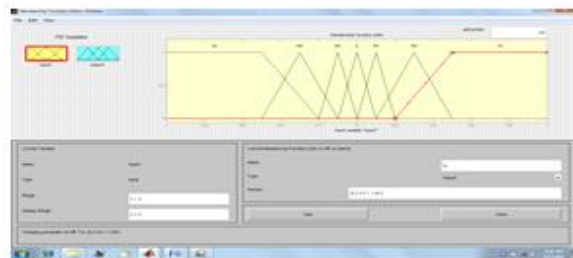


Fig. 6. Linguistic rules for angle ( $\alpha$ ) determination for driver circuit. It will for a) speed error. b) Change in speed error. c) Change of alpha

TABLE II. THE RULE DATA BASE

cs	NL	NM	NS	Z	PS	PM	PL
NL	PL	PL	PL	PL	NM	Z	Z
NM	PL	PL	PL	PM	PS	Z	Z
NS	PL	PM	PS	PS	PS	Z	Z
Z	PL	PM	PS	Z	NS	NM	NL
PS	Z	Z	NM	NS	NS	NM	NL
PM	Z	Z	NS	NM	NL	NL	NL
PL	Z	Z	NM	NL	NL	NL	NL

#### IV. DRIVER CIRCUIT AND MODELING

DC chopper has been used to drive the motor also changes average value of load voltage applied from a fixed DC source by switching a power switch.

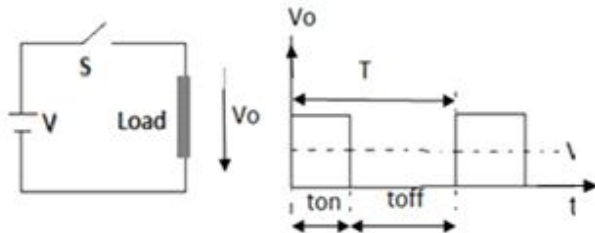


Fig 7. Operating principle and output waveform of Driver  
Using Fig 7, the average output voltage can be calculated as

$$V_{do} = \frac{t_{on}}{t_{on} + t_{off}} V \quad (4)$$

Where V is the DC source voltage.  $v_{do}$  can be controlled using three methods:

- \*Hold  $t_{off}$  fixed and change  $t_{on}$  (frequency modulation)
- \*Hold period ( $t_{on} + t_{off}$ ) fixed and change  $t_{off}/t_{on}$  rate (pulse width modulation)
- \*change  $t_{off}$  and  $t_{on}$  separately. (Combination of first and second method)

One-quadrant DC chopper and general waveforms for continuous current conditions are shown in fig.8

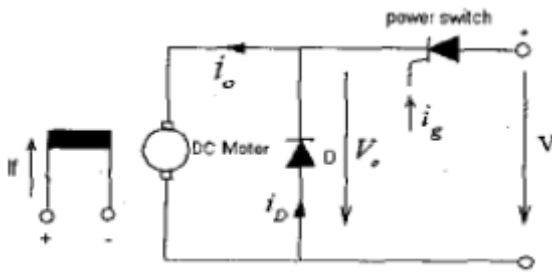


Fig 8. simple power circuit of a one quadrant DC chopper

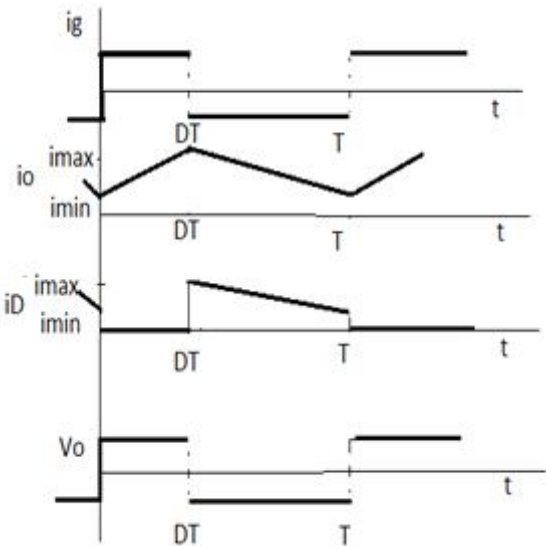


Fig 9. General waveform for current continuous condition

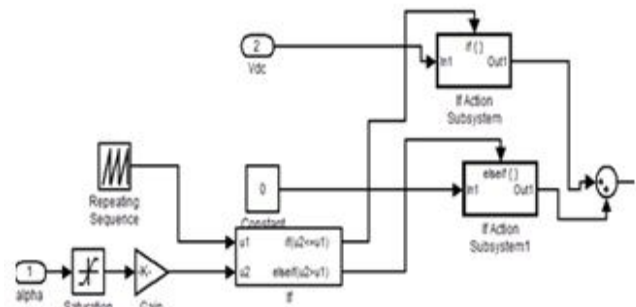


Fig. 10. DC Chopper model

Fundamentally, the operating principle of driver model is based on the comparison of two signals [7]. One of the signals is a triangular waveform which represents one PWM is used to control average output voltage period of 2 KHz chopping frequency and other one is fixed linear signal which represents time equivalent of alpha triggering ( $t_a$ ). Since chopping frequency is 2 KHz, the amplitude of triangular waveform starts from zero and reaches  $1/2 \cdot 10^3 = 0.0005$  value. On the other hand, the alpha signal from controller is multiplied by  $0.0005/360$  value to calculate the time corresponding to this angle. Alpha signal and triangular signal are  $U_1$  and  $U_2$  variables of '1F' block used in simulation model shown in Fig. 10, respectively.

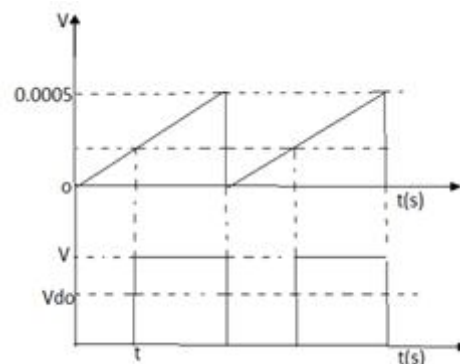


Fig 11. input and output signal of driver model

## V. CONTROL SIMULATION

In FLC model gain1, gain2 and gain3 define change of error, error and change of alpha scaling factors respectively. Simu

lation results are shown for 50 nm load applied at 0.6s. Simulation result for PI controller for loaded and no loaded condition is shown in table iii

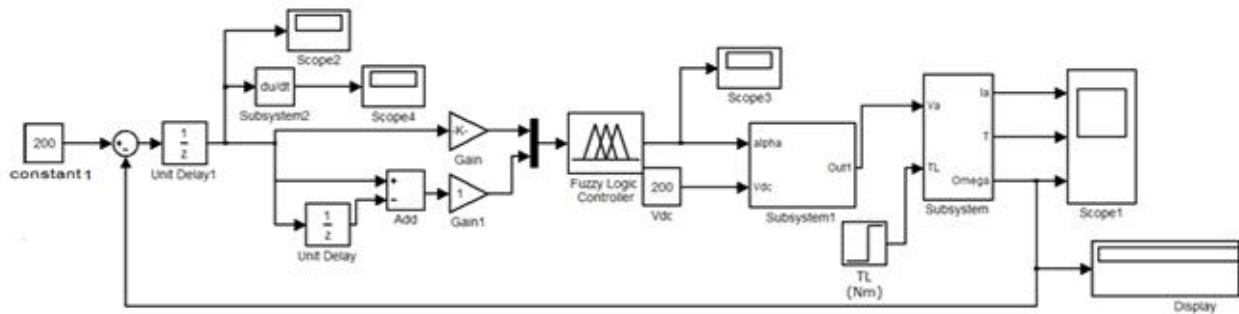


Fig 12. Fuzzy Logic Controller Simulink model

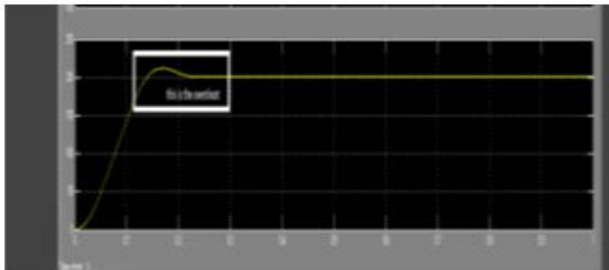


Fig 13. a) Speed response of PI controller for used motor

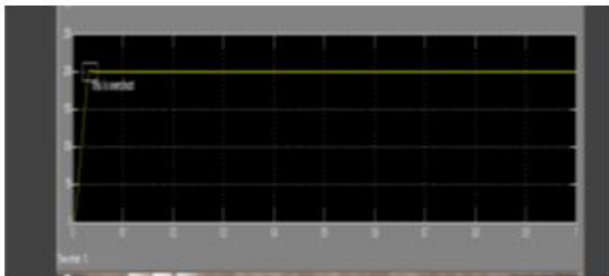


Fig 13. b) Speed response of Fuzzy controller for used motor

TABLE III PERFORMANCE ANALYSIS OF SYSTEM

$C1: K_p=100, K_i=15$   $T_r$ : Rise time  
 $C2: K_p=200, K_i=25$   $e_{ss}$ : Steady state error  
 $C3: K_p=300, K_i=28\%$   $M_p$ : Percentage Maximum overshoot  
 $C4: K_p=500, K_i=30$   $C1, C2, \dots$  Different  $K_p$  and  $K_i$  coefficients

(a) For different loads

		Load	10N	30N	50N
P I	C1	$\%M_p$	5.955	5.045	5.527
		$e_{ss}$	-0.393	-0.288	-0.191
	C2	$\%M_p$	5.633	5.6313	5.632
		$e_{ss}$	-0.25	-0.195	-0.15
	C3	$\%M_p$	5.7315	5.7315	5.7315
		$e_{ss}$	-0.18	-0.15	-0.12
	C4	$\%M_p$	5.895	5.895	5.895
		$e_{ss}$	-0.1175	-0.09	-0.075
FLC	$\%M_p$		0.81	2.04	4.93
	$e_{ss}$		0.0062	-0.0045	-0.018

(b) Unloaded operation

Criteria	PI				FLC
	C1	C2	C3	C4	
$T_r$	0.141	0.141	0.141	0.141	0.036
$e_{ss}$	-0.933	-0.579	-0.415	-0.262	-0.01
$\%M_p$	5.527	5.631	5.731	5.894	0.68

Percent overshoot ( $\%M_p$ ) and steady state error ( $e_{ss}$ ) are measured for different load.

## CONCLUSION

Fuzzy Logic Controllers are a suitable option to make speed regulation in DC motors and AC motors. The quality of the control obtained with FLC's at the first tries is commonly good because is based on the knowledge of an expert. It can not be said the same about conventional controllers. The single human based reasoning used on a FLC can be very useful to overcome nonlinearities of any kind of plants in a logical way. The experience gained from these works has allowed us to attack another systems of very different nature obtaining satisfactory results. Comparison between PI controller responses and FLC responses is shown in table iii and shows that FLC gives better performance than PI controller in terms of overshoot, steady state error and rise time. Also show that FLC is more sensitive to load changes. It would be necessary to use a more complex intelligent control system, i.e. Adaptive Fuzzy System, Neuro-Fuzzy System, in order to obtain a better performance on speed control

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